IDAX Application Guide – DFR Measurements on Current Transformers

Abstract:

Revision history

Date	Revision	Comments
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1 Medium and High Voltage Current Transformers

1.1 General Information

Design features of Current Transformers at Medium and High Voltage levels need to be briefly reviewed for further understanding of the use of IDAX to diagnose the insulation system of these devices. This document discusses the application of testing techniques to oil-immersed current transformers of the substation type.
Current Transformers (CTs) are critical components within the electrical infrastructure. The electrical Industry, whether related to generation, transmission or distribution of electrical energy, requires of CTs for the purpose of measurement and protection. Even though these devices are used for protection of major components of the system and to provide continuity of operation, CTs are not protected by any local or remote monitoring instrumentation. Therefore, testing of these critical components by reliable technology, as well as a proper understanding and interpretation of results is of major interest for manufacturers and operators worldwide.
In this application note, some of the most common designs are briefly described and testing analysis is presented exclusively as applied to Current Transformers of the Oil-Immersed type of insulation.

1.2 Risk of Unknown Conditions during Operation

Accurate evaluation of moisture content in the oil-paper insulation system of instrument transformers is a concern for many utility operators worldwide. Water significantly accelerates ageing of cellulose. Oil analyses by means of Karl Fischer titration (KFT) have traditionally been used for the evaluation, assuming existence of equilibrium in distribution of moisture between oil and paper/pressboard but unless a direct sample is taken from the solid insulation, this analysis will only reflect the moisture % in the liquid insulation. In addition, for oil sampled at low temperature, the equilibrium curves are not very accurate, which additionally introduces uncertainty in the estimates of moisture content.
Failure of a substation type oil-immersed current transformer can lead to a high energy explosion. Because of the difference in thermal expansion ratio between the metallic housing of the CT and the relatively fragile porcelain insulator, mechanical stress builds up that may result in a blast where fragments from the porcelain insulator may reach up to 50 m from the location of the unit. Loss of this important device results in phase to ground fault that will trip the operation of a substation. Reliability of the energy system is a consolidated value where major components and critical components should be evaluated. A link is not stronger than its weakest link.

Figure 1. Failure of a Current Transformer of the Substation Type

Certainly, operators do not want to have a similar to **Error! Reference source not found.** picture taken in their facilities. Maintenance in the electrical industry and especially in the transformer business is moving from a Preventive Programmed Maintenance to Condition Based Maintenance and new technology is now available to operators for a better assessment of such valuable devices.

1.3 Construction of Current Transformers

1.3.1 Outdoor Molded Epoxy, Wound Type, Metering Relaying CT (15, 25, 34.5, 46, 69 kV)

The core and coil assembly is wound and encapsulated in a high dielectric strength epoxy resin to provide high withstand capabilities. The external line to ground insulation consists of a cycloaliphatic epoxy resin that provides excellent arc track properties in addition to UV resistance and strong physical strength. A high voltage stress ring around the top of the unit is supplied to limit corona.

Figure 2. Track Resistant Cycloaliphatic Epoxy Design

Figure 3. Outdoor 46kV, Molded Epoxy, Wound type, Measurement CT

1.3.2 Outdoor Molded Resin, Window Type, Metering/Relaying CT (5, 8.7, 15, 25, 34.5 kV)

This is a dry type, solid cast CT able to operate with high accuracy for metering or relay applications. The core and coil assembly is wound and encapsulated in a molded cast resin with a standard 4.44” window to provide high withstand capabilities. RF: up to 4.0**.**

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Figure 4. 5kV Dry-type solid-cast CT

1.3.3 Type COF Outdoor Oil-Filled, Wound Type, Metering/Relaying CT (15, 25, 34.5, 46, 69, 115, 138, 161 kV)

Figure 5. 69kV Oil-filled Wound Type Metering CT

The tank dome is fabricated from carbon or stainless steel, depending on current rating. The units are pressure and vacuum tight and hermetically sealed at the factory to prevent breathing and oil contamination. Tank components are washed and coated with anticorrosive iron phosphate and then finished with ANSI 70 Gray baked-on electrostatic polyester powder. The bushing is high strength porcelain with a high degree of stability for transportation and seismic withstand. RF: up to 1.5

1.3.4 Type CA Outdoor Oil-Filled, Wound Type, Metering/Relaying CT (230, 345, 500, 765 kV)

Figure 6 Outdoor 230kV Oil-filled wound Type, Metering CT

This specific design is for Voltages of 230kV and over. The tank dome is fabricated from corrosion resistant aluminum and contains stainless steel expansion bellows to allow for the expansion / contraction of oil for temperature and load fluctuations. The bellows maintain constant pressure on the oil under various ambient and load conditions to allow for horizontal shipment. Base components are shot-blasted, washed and coated with a heavy galvanized finish. The primary bushing is ANSI 70 Gray, high strength porcelain with a high degree of stability for transportation and seismic withstand. An adjustable primary spark-gap is provided for all units to protect from high transients. The unit is fitted with an oil level indicator and oil sampling drain valve. The unit can be manufactured in single, dual or multiple core design. RF: up to 4.0

1.3.5 Type IOSK Outdoor Oil-Paper Insulation Current Transformer

Head type design of low weight and minimum oil volume: These units have good seismic performance. The primary could be of the bar-type or bare-conductor type sized properly to withstand short circuit currents and to avoid large voltage drop across the primary winding. The secondary winding is distributed uniformly in order to obtain accurate transformation. These units provide stable accuracy over long periods of time. Expansion bellows are located on the top of the unit to allow oil expansion.

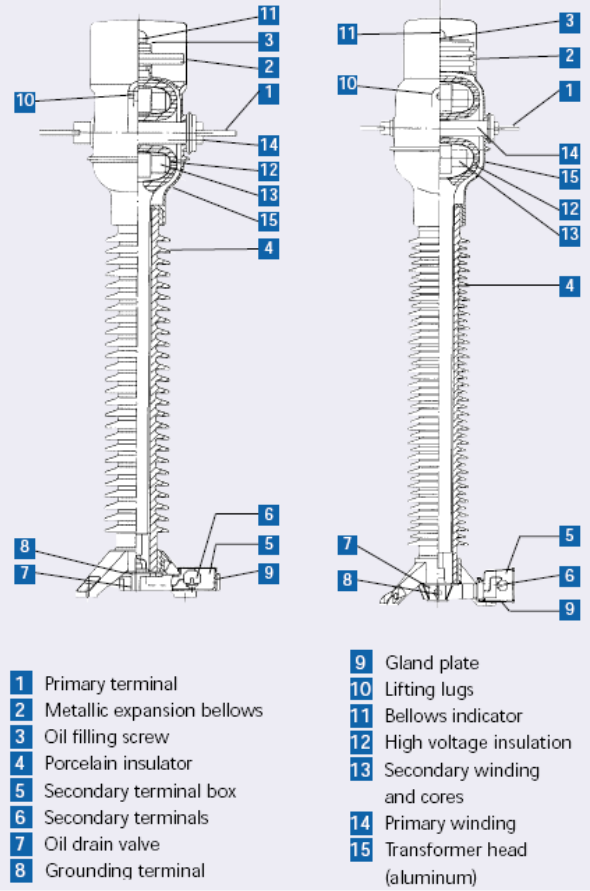

Figure 7 IOSK Oil-immersed CT - Design Details

Trench Group presents two designs, one for voltages from 72.5 to 170 kV and the other one for voltages in the range from 245 to 550 kV.

1.3.6 Type OSKF outdoors Oil-Paper insulation Current Transformer

Trench type OSKF Current Transformers are defined as "head type" Current Transformers. These CT's are designed and constructed with the well proven, highly reliable, oil/paper insulation system. Each porcelain-housed, hermetically sealed, current transformer is equipped with stainless steel expansion bellows, calibrated to the internal oil volume and extremes in operating and ambient temperatures.

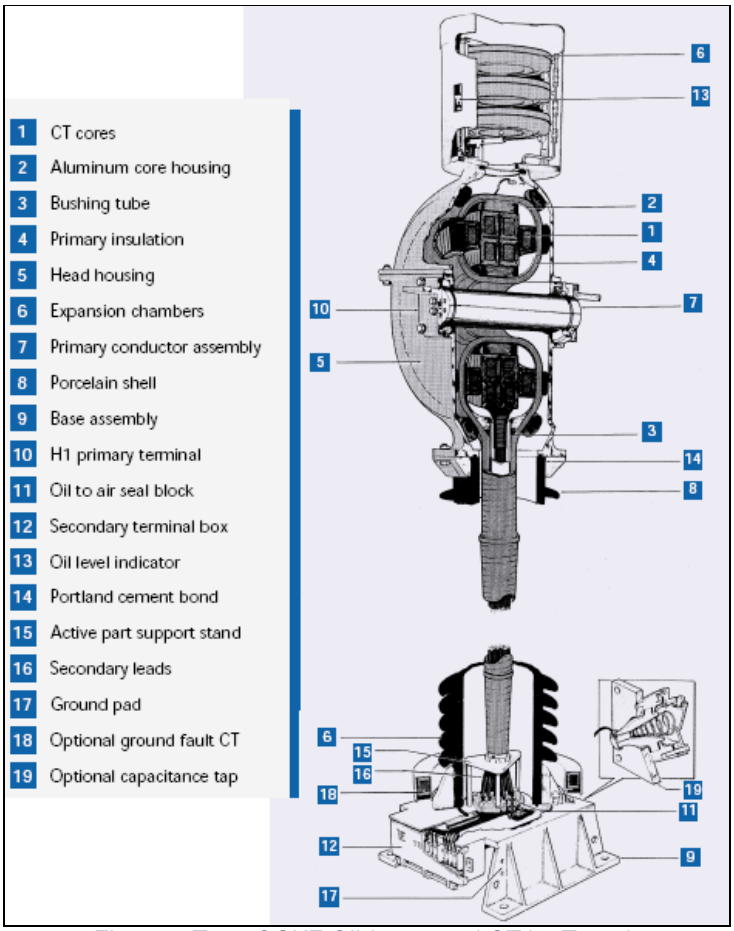

Figure 8 Type OSKF Oil-Immersed CT by Trench

The custom designed; toroidally wound cores are located in the head of the unit. The core housing can accommodate up to six independent multi-ratio relaying cores or a combination of relaying and metering cores requiring up to 30 secondary leads.
The previous figures reflect the typical Trench Group designs for CT's from 72.5 to 800kV, the following design (**Error! Reference source not found.**) is a more conservative design used for voltages from 25kV to 230kV. The IK5 head-type design below is hermetically sealed using nitrile rubber gaskets. Normally this design will incorporate a dry nitrogen cushion above the oil to compensate for oil volume changes. All these designs are single core with dual ratio, tapped secondary winding.

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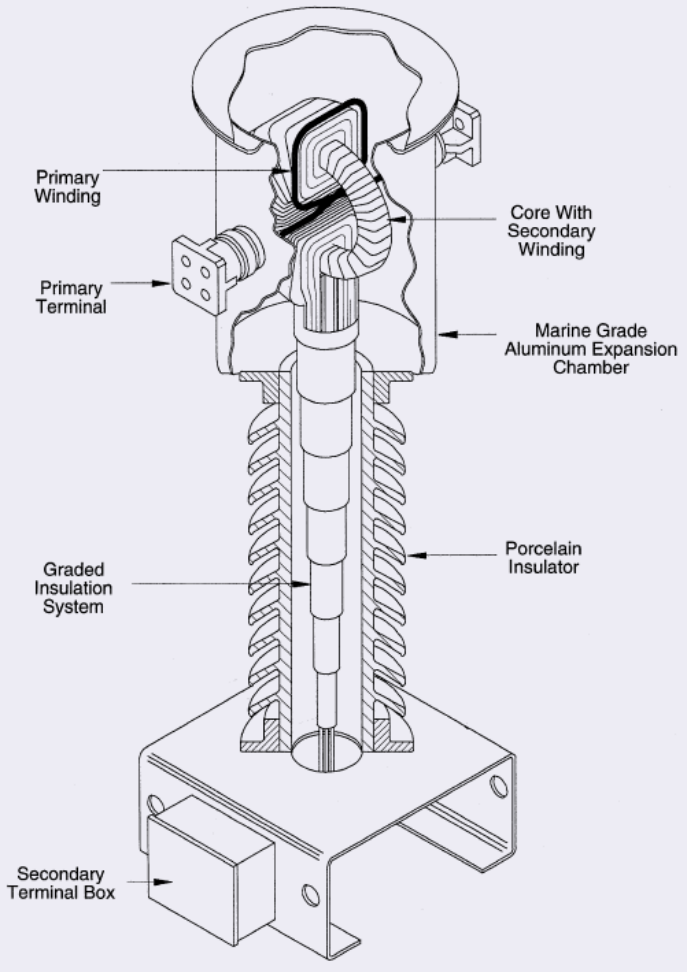

Figure 9 Typical IK5 Oil-Immersed CT

1.3.7 Outdoors Gas-Insulated Current Transformers

These units are available for voltages from 72.5 to 800kV. SF6 has been recognized as a non-toxic, inert and non-flammable insulation medium. Therefore, SF6 compressible insulation medium is an explosion-proof design. According to manufacturers, these units have no insulation ageing and a minimum risk of failure.
Gas is monitored by a density meter, guaranteed SF6-leakage rate of less than 1% per year.
Transformer operates at rated voltage, even in the case of loss of SF6-pressure.
Head-type Gas Insulated Current transformers are found in the market for primary currents in the range 100A up to 4800A. Core changes after assembly do not require the destruction of the high voltage insulation.

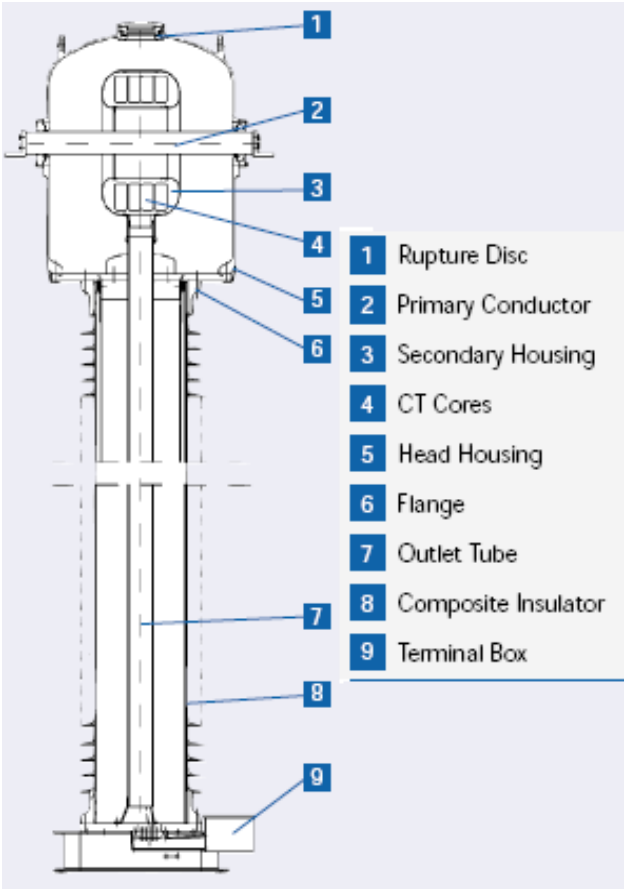

Figure 10 Gas Insulated CT

Error! Reference source not found. summarizes the above described construction designs for Current Transformers primarily used in North America.

Current Transformer Design	Rated Voltage (kV)													
	5	8.7	15	25	34.5	46	69	115	138	161	230	345	500	765
Outdoor Molded Epoxy, Wound Type			✓	✓	✓	✓	✓							
Outdoor Molded Resin, Window Type	✓	✓	✓	✓	✓									
COF Outdoor Oil-Filled, Wound Type			✓	✓	✓	✓	✓	✓	✓	✓				
CA Outdoor Oil-Filled, Wound Type (c/w bellows)											✓	✓	✓	✓
Oil-Filled, Wound Type, Single Phase Metering Combined CT/VT unit			✓	✓	✓									
IOSK Outdoors Oil-Paper (c/w bellows)							✓	✓	✓	✓	✓	✓	✓	
OSKF Outdoors Oil-Paper (c/w bellows)							✓	✓	✓	✓	✓	✓	✓	✓
IK5 Head-type Oil-Paper insulation				✓	✓	✓	✓	✓	✓	✓	✓			
Outdoors Gas-Insulated (SF_6)							✓	✓	✓	✓	✓	✓	✓	✓

Table 1 Typical CT Designs for MV / HV Applications

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2 DFR measurements on Current Transformers

2.1 Measurement Setup

For oil-immersed CTs, measurements are carried out following the general safety recommendations described in section 1.6.1 of the IDAX User's Manual.
Remember that the unit should be off-line and the unit under test should preferably have stabilized temperature variation after operation. The average temperature of the insulation must be measured/estimated and recorded. One option is to measure on several positions on the outside of the CT with a Pistol Grip Laser Target Temperature Gauge or if the unit has not been in operation recently, insulation temperature is assumed to be the same as ambient temperature

Figure 11 IDAX test on new CTs

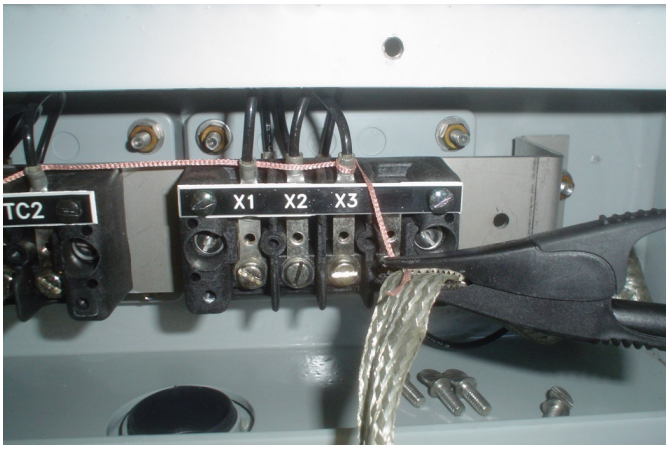

Figure 12 Secondary winding in GST-General Specimen connection

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Recommended test setup is GST (Grounded Specimen Test) applying test voltage to the HV terminal. LV terminal should be grounded. See figures 11 to 14.

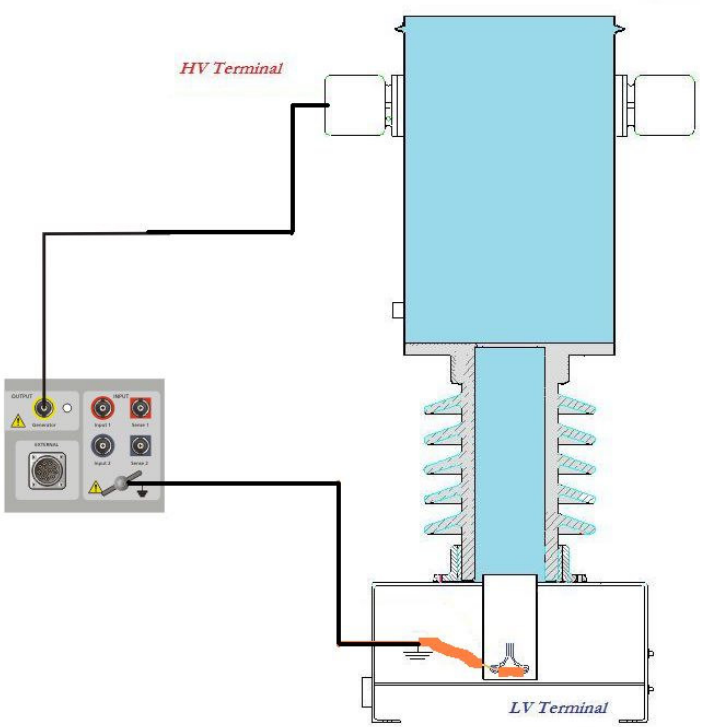

Figure 13 GST - without guard

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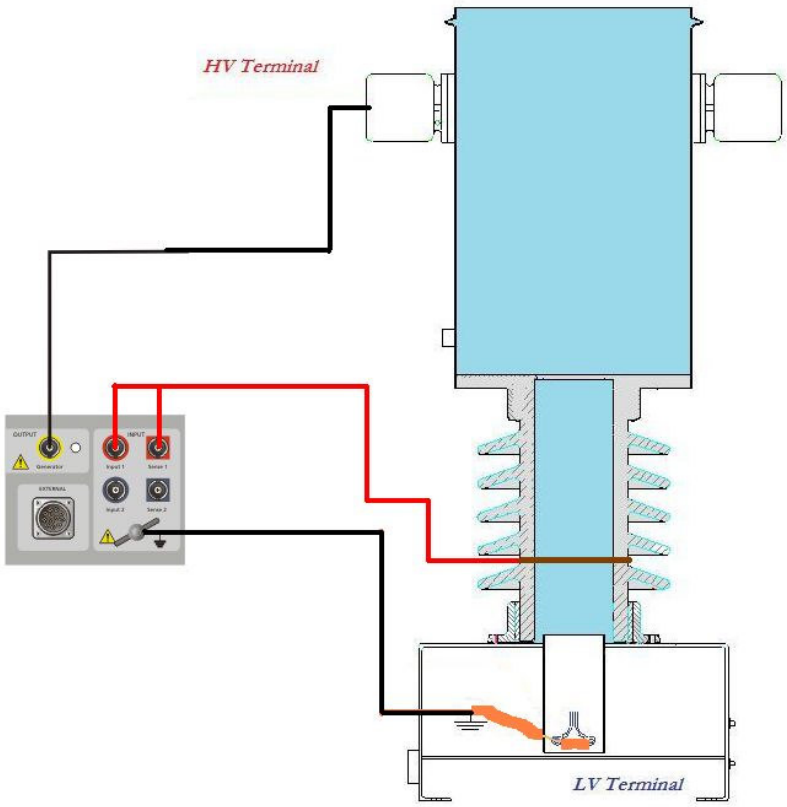
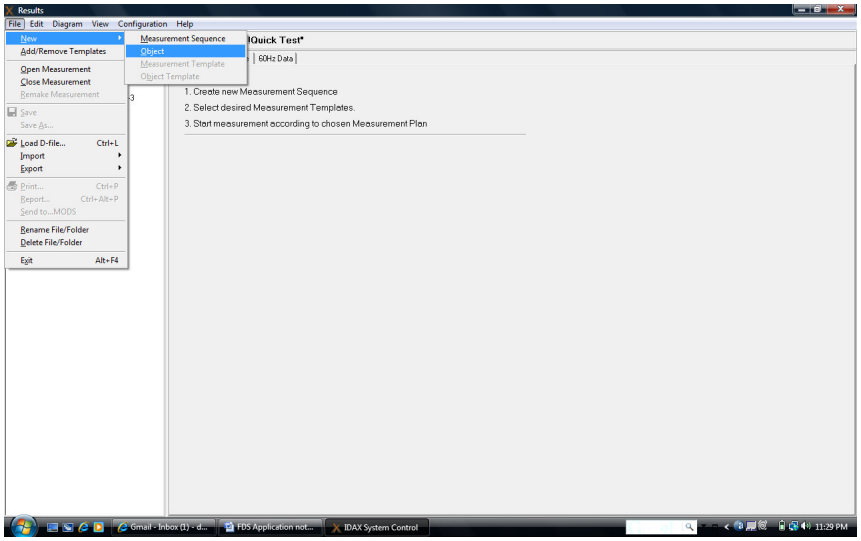


Figure 14 Measurement CT - GST with guard connection

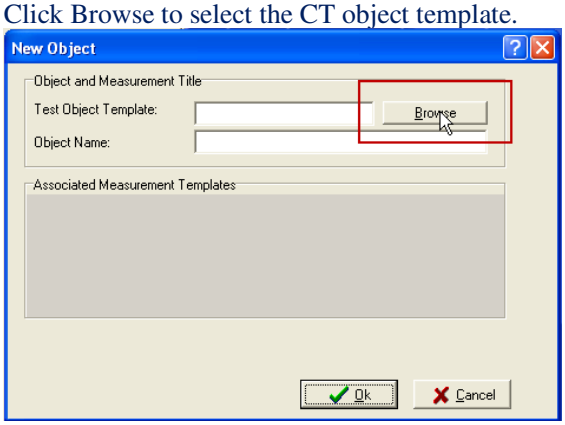
2.2 Step-by step procedure

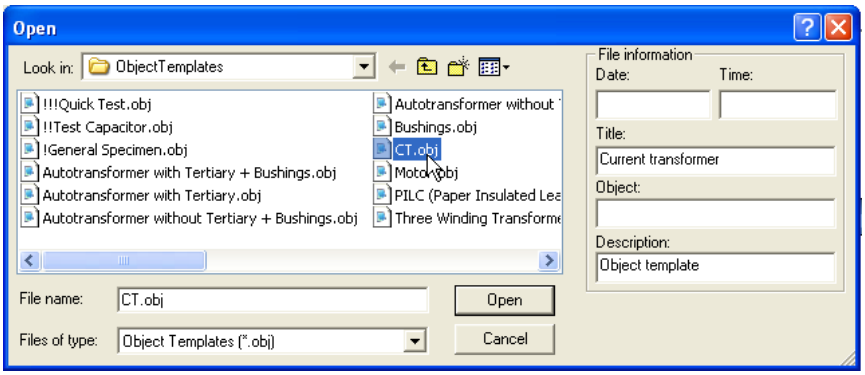
In order to measure and analyze an oil-immersed current transformer, the following steps should be followed:

- Start IDAX – Control and go to the application Result.
- Go to File – New – Object



- A “New Object” window will open for you to provide the main information of the unit
- Click Browse to select the CT object template.





- Name the object using a name that is descriptive as this is the name that will be seen in the object browser. Click OK to create the object.

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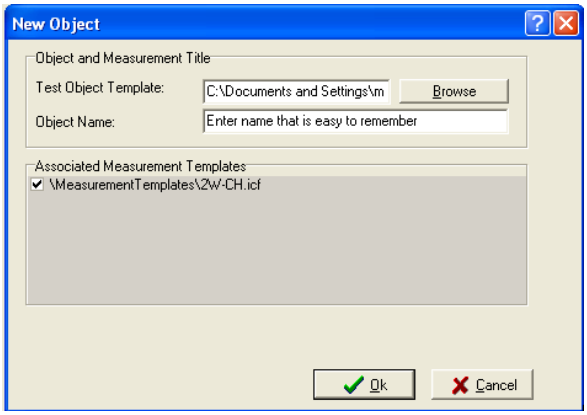
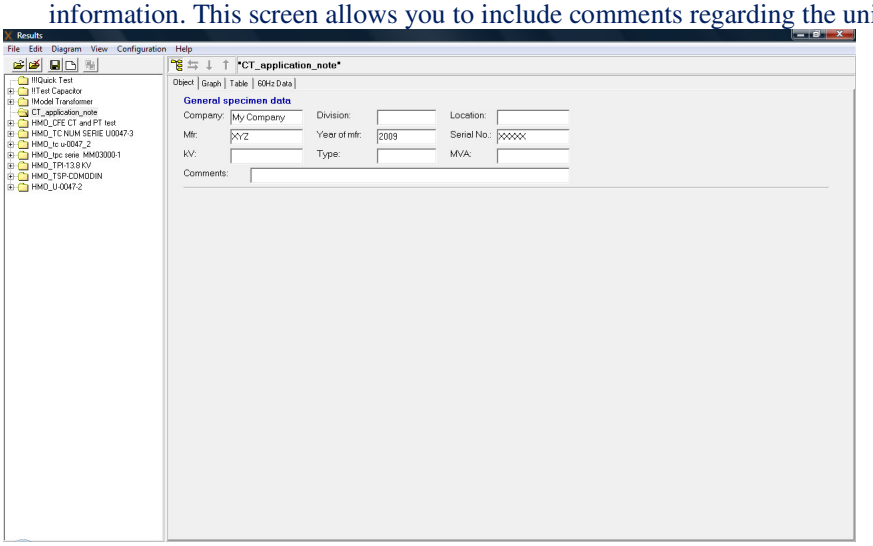


- When the Object has been created, fill all fields with requested name plate information. This screen allows you to include comments regarding the unit.



- Go to File – New – Measurement Sequence and provide the data requested. Make sure you have entered the average insulation temperature! Your menu will have now all information ready to initiate testing.

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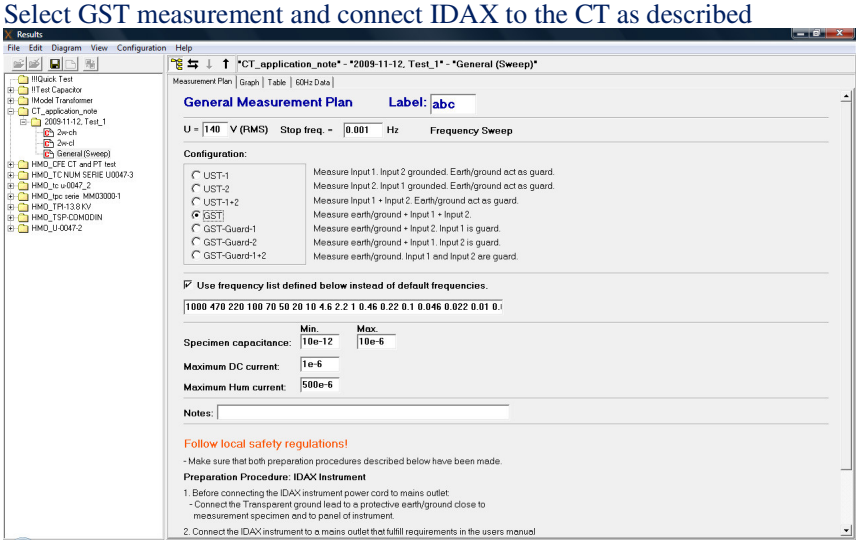
- Select GST measurement and connect IDAX to the CT as described


Results
File Edit Diagram View Configuration Help
CT_application_note - *2009-11-12, Test_1* - *General (Sweep)*
Measurement Plan Graph Table 60Hz Data
General Measurement Plan
Label: abc
U = 140 V (RMS) Stop freq. - 0.001 Hz Frequency Sweep
Configuration:
UST-1
UST-2
UST-1+2
GST
GST-Guard-1
GST-Guard-2
GST-Guard-1+2
Measure Input 1. Input 2 grounded. Earth/ground act as guard.
Measure Input 2. Input 1 grounded. Earth/ground act as guard.
Measure Input 1 + Input 2. Earth/ground act as guard.
Measure earth/ground + Input 1 + Input 2.
Measure earth/ground + Input 2. Input 1 is guard.
Measure earth/ground + Input 1. Input 2 is guard.
Measure earth/ground. Input 1 and Input 2 are guard.
Use frequency list defined below instead of default frequencies.
1000 470 220 100 70 50 20 10 4.6 2.2 1 0.46 0.22 0.1 0.046 0.022 0.01
Min. Max.
Specimen capacitance: 10e-12 10e-6
Maximum DC current: 1e-6
Maximum Hum current: 500e-6
Notes:
Follow local safety regulations!
- Make sure that both preparation procedures described below have been made.
Preparation Procedure: IDAX Instrument
1. Before connecting the IDAX instrument power cord to mains outlet:
- Connect the Transparent ground lead to a protective earth/ground close to measurement specimen and to panel of instrument.
2. Connect the IDAX instrument to a mains outlet that fulfill requirements in the users manual

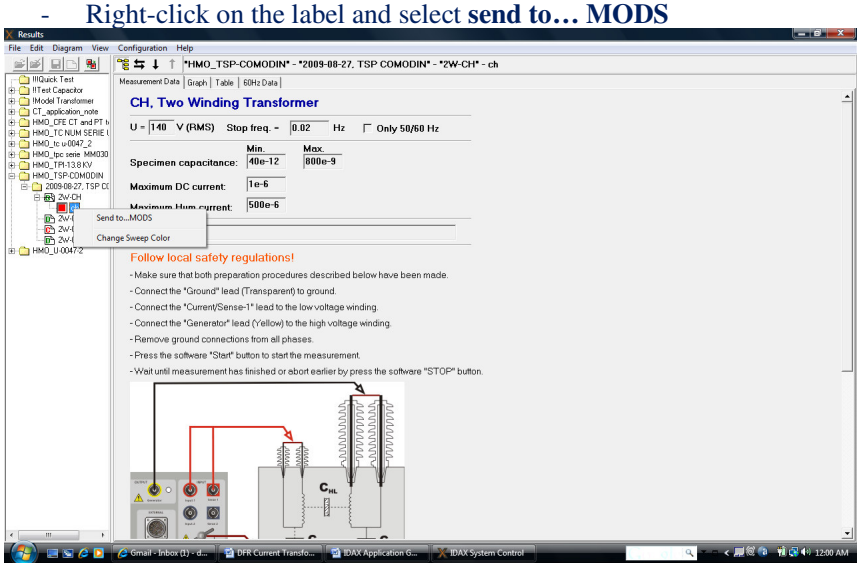
- Input the information and you are ready to start the test with your IDAX-300.
- Select/highlight the actual test file(GST)
- Start measurement

3 Moisture Analysis

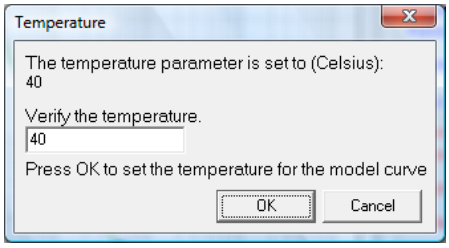
Megger MODS is used for the moisture analysis. For details on the program and insulation modeling technique, please see the MODS User manual.

3.1 Step-by-step procedure

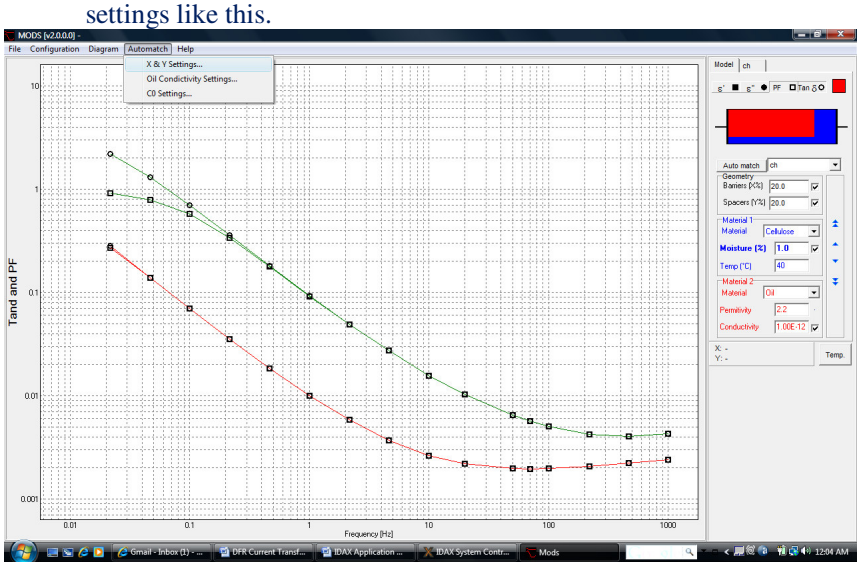
- Open the Sweep you want to analyze
- Right-click on the label and select **send to… MODS**

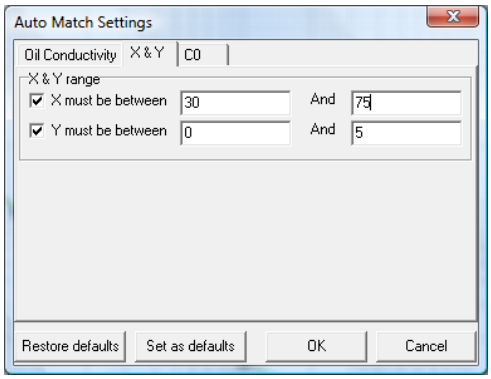

Results
File Edit Diagram View Configuration Help
HMO_TSP-COMODIN - *2009-08-27, TSP COMODIN* - *2W-CH* - ch
Measurement Data Graph Table 60Hz Data
CH, Two Winding Transformer
U = 140 V (RMS) Stop freq. - 0.02 Hz Only 50/60 Hz
Min. Max.
Specimen capacitance: 40e-12 800e-9
Maximum DC current: 1e-6
Maximum Hum current: 500e-6
Send to...MODS
Change Sweep Color
Follow local safety regulations!
- Make sure that both preparation procedures described below have been made.
- Connect the "Ground" lead (Transparent) to ground.
- Connect the "Current/Sense-1" lead to the low voltage winding.
- Connect the "Generator" lead (Yellow) to the high voltage winding.
- Remove ground connections from all phases.
- Press the software "Start" button to start the measurement.
- Wait until measurement has finished or abort earlier by press the software "STOP" button.

- Confirm/change/enter the insulation temperature



- Select CT material database
- We recommend that you Confirm/change the default automatch settings when you use MODS for CT analysis. If you only analyze CT's you can leave the settings like this.





- Do not forget to change back before doing moisture analysis on power transformers!
- Click auto match in the main screen
- Wait for the curve matching process to finish.
- Read moisture level (Below example show 2.4% moisture)

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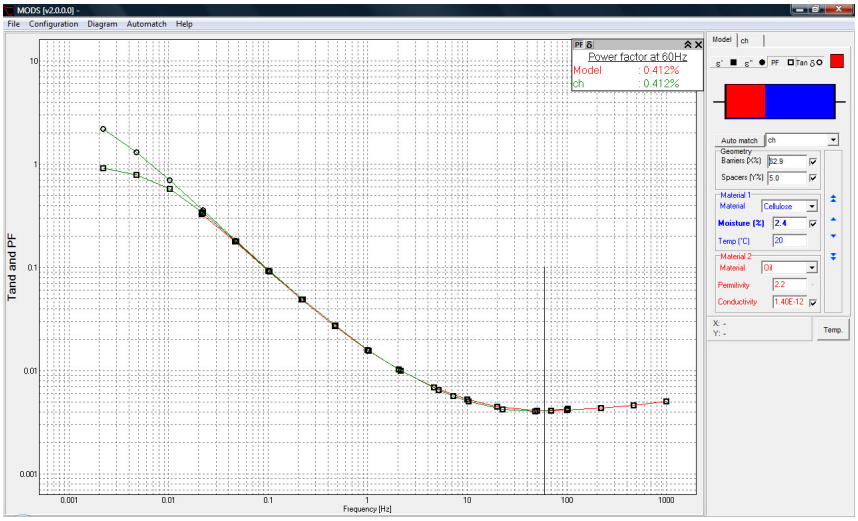
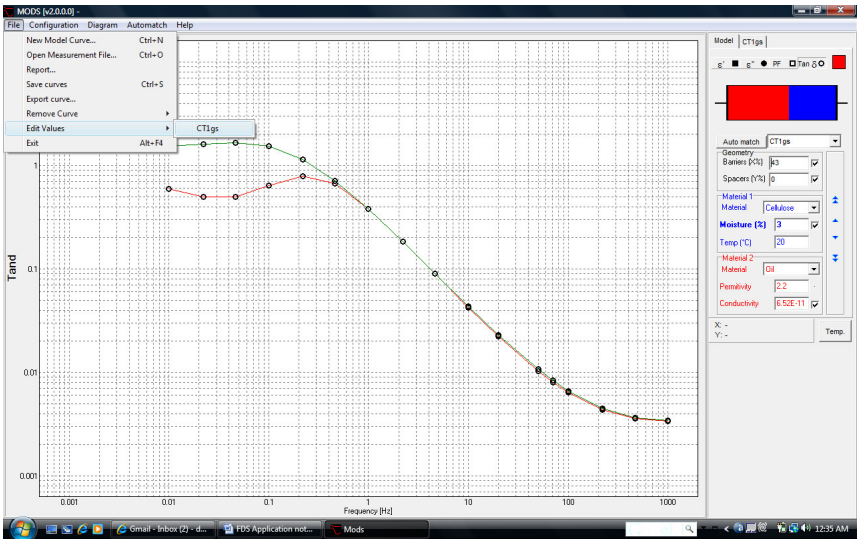


3.2 Comments on IDAX measurements on CTs

- GST measurements have been selected since many CT's do not have a test tap. GST measurements are possible to perform on all types but have the disadvantage of being sensitive for leakage currents on the outside of the unit. Normal procedure to prevent this is to make sure the unit is dry and cleaned before the test. Recording ambient temperature and humidity is always recommended in case the analysis is questionable. Measuring GST guard using a conductive collar strap can also reduce leakage currents on the outside enclosure of the tested device.
- The conductivity of the oil reflects the degree of ageing of the unit and the subsequent contamination due to the byproducts normally obtained from the cellulose and liquid degradation. A brand new transformer typically has oil conductivity in the E-15 range. Therefore, if any characteristic is moving below this range, set the Oil Conductivity to 1.00E-14 and uncheck the checkbox next to the oil conductivity field.
- A conductivity value above 5.00E-11 is an indication of carbon sediments and overheating of the solid insulation.
- Moisture in the solid insulation is temperature dependent. Make sure to correctly estimate the test objects temperature. Refer to your manufacturer manual for the heat run test analysis that can provide information about of the expected temperature at certain load levels. Best scenario of course is to allow for cool down to a stable temperature prior to running the test.
- Current transformers are available in different types and constructions, but they normally have an oil level gage. Confirm that the oil level in the tank is ok.
- Some test sweeps are more difficult to analyze than others. "Out of bound" values due to noise interference and/or spurious currents can be eliminated by selecting File - Edit Values



4 Classification

For validation of the results and better understanding of possible moisture increase within the insulation system, aged units presented values of 4% and above. Therefore, it is suggested to consider the following values for reference:

GOOD CONDITION	NORMAL AGEING	QUESTIONABLE CONDITION
0.5 – 2.0%	2.0% - 4.0%	>4%

5 Accuracy

Compared to moisture assessment in oil-immersed power transformers, moisture estimation in CT's is a relatively unexplored application. However the basic theories on insulation modeling are well proven and there is no reason to believe that this application should be significantly different from the power transformer application.

The accuracy in moisture estimation in oil-immersed current transformers (head type) is estimated to ± 20% of reading ± 0.2% for moisture levels 1-4% and insulation temperature 15-40 °C. These numbers can improve as more measurement data and laboratory results are added to our measurement database.

6 EXAMPLES

6.1 CT OSKF-123 0.3B2.0 / C400 RF 1.2.

This unit has a power factor value @ 60Hz of 0.19% and the moisture content is 1.5%. Conductivity of the oil is very low which indicates a good dielectric breakdown value and no by-products contamination.

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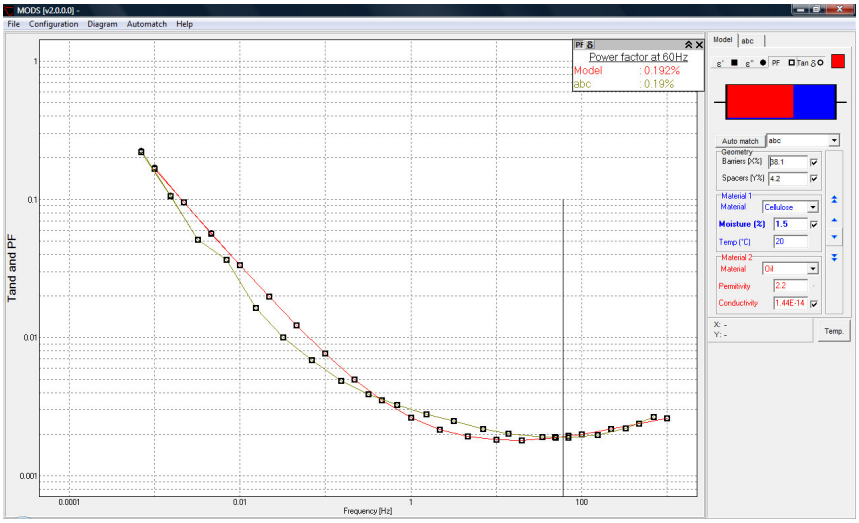

Figure 15 IDAX Test on OSKF-123

6.2 CT OSKF-123 C400/C800 RF 1.5.

When the test is carried out on an instrument transformer, it is important to consider a minimum amount of Y% (0-5) because the solid insulation is mainly paper wrap. The analysis generates a 0.262% PF value reflected in 2.9% moisture content in cellulose but a very low conductivity of the oil. Another important factor to be considered is the rated nominal voltage of the unit; this creates a difference based on the ratio of oil / paper insulation. Interesting to highlight here is that similar size units are used for different current ratios.

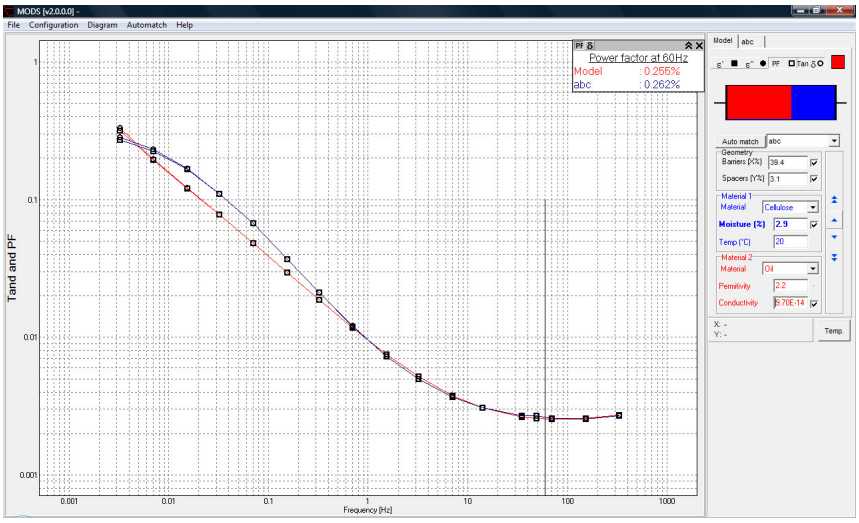

Figure 16 IDAX Test on OSKF-123

6.3 CT OSKF-72.5 0.1PL335 1250:1

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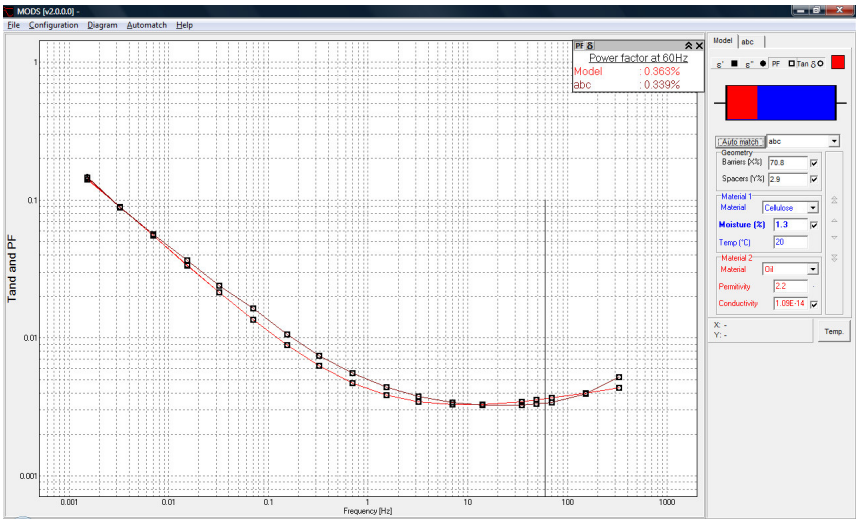
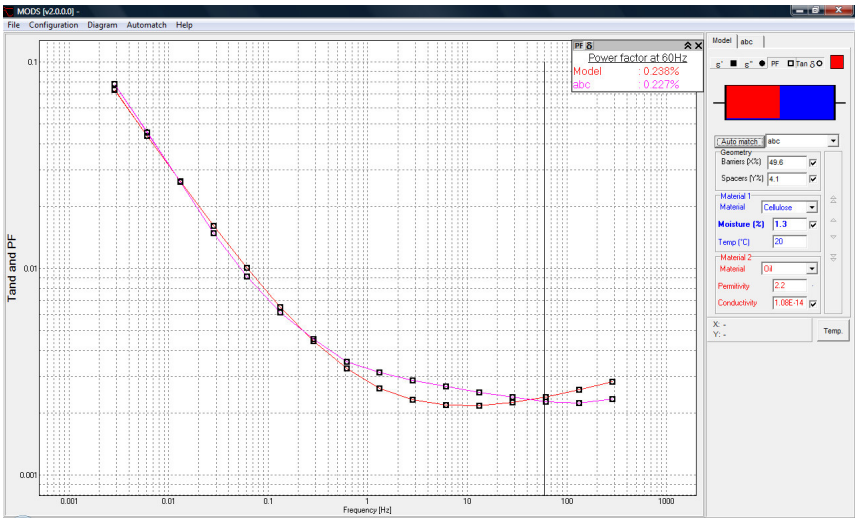


Figure 17 IDAX Test on OSKF 72.5

An example of the advantage with frequency sweep vs. PF at Mains frequency. The %PF is 0.339%; this value is higher than the previous examples but the moisture in the solid insulation is only 1.3% and the conductivity of the oil is very low.

6.4 CT OSKF-245 0.3B1.8 / 10L800 RF 1.0.



This unit has the same result as the previous examples but with completely different insulation geometry.

Figure 18 IDAX Test on OSKF-245

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6.5 CT OSKF-145ER 0.15B1.8 RF 2.0.

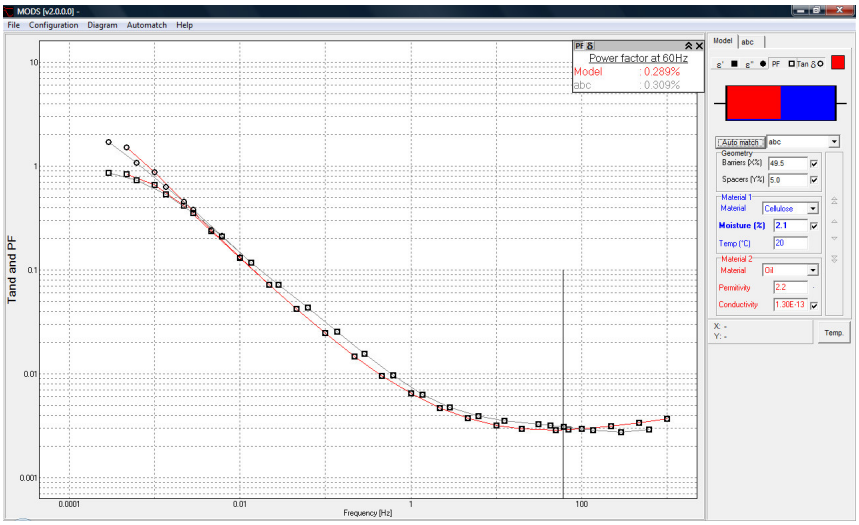

Figure 19 IDAX Test on OSKF-145ER

This unit has a high PF% value of 0.309% as well as higher oil conductivity (1.3E-13) than above units. These values would be investigated further using Partial Discharges and HV Impulse Test in a factory but in a substation this unit shows normal ageing and does not require maintenance as moisture is at an acceptable level.

6.6 COF-350 CT 0.3B1.8 RF 1.5/2.0.

This example is interesting as it illustrates the capabilities of the IDAX. This unique example does not reflect a typical maintenance situation but shows the capability and accuracy of the method by comparing results before, after the repair when the paper has been subjected to ambient air and finally after final oil and vacuum process.
The reason for the repair was that one of the high-voltage terminals leaked oil and not a moist insulation. The owner wanted to seal the leak by replacing the O-rings and corresponding gaskets, and put it back to service.

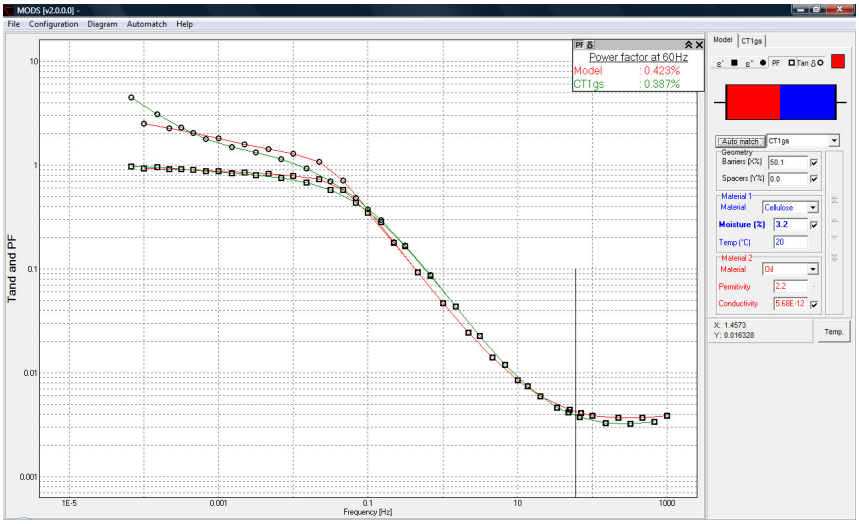

Figure 20 IDAX Test on COF-350 with GS Template

The unit presents a 0.387% PF at 60Hz, which is still within acceptable values. If this was the only available analysis then the PF test is just a YES/NO test. Let's look at all the information obtained from IDAX after the analysis with MODS. **Error! Reference source not found.** summarizes the results obtained.

	Capacitance	Moisture Content (%)	Oil Conductivity (S/m)	PF@60Hz (%)
GST	9.8E-11	3.2	5.68E-12	0.387

Table 1 Summary of IDAX Test on COF-350 before opening the unit

This test reflected clear contamination of the liquid insulation by ageing by-products.

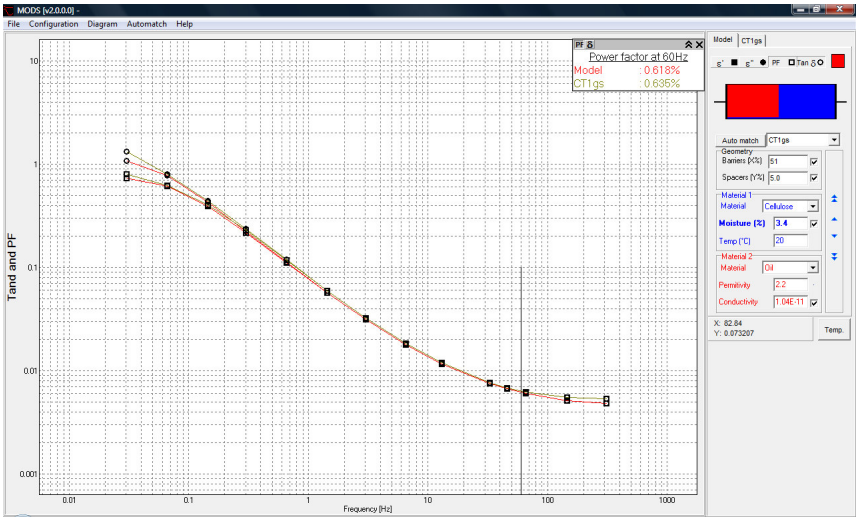

Figure 21 IDAX Test on COF-350 after terminal replacement - connection GST

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After replacement of gaskets and O-rings of the high voltage terminal, the value of PF increased above acceptable values. Oil conductivity and moisture content also increased. This example clearly shows the benefits of using the wide frequency sweep instead of only one power frequency reading.
The unit was opened and the failure fixed. Now the owner wanted to identify how this work affected the unit. Therefore, the same test was carried out following exactly the same procedure. Again, the insulation diagnostics device provides specific location of the possible contamination. As a matter of fact, the oil exposed for a long period of time to the atmosphere absorbed the moisture and this is perfectly reflected in the test. Then, the physical problem was fixed, but the unit cannot get back to operational conditions? Then, why is someone going to do that?
A summary of the results is presented in **Error! Reference source not found.**.

	Capacitance	Moisture Content (%)	Oil Conductivity (S/m)	PF@60Hz (%)
GST	1.18E-10	3.4	1.04E-11	0.635

Table 2 IDAX test on CT after replacement the damaged HV Terminal

Let's look at the readings after heating and vacuum filtration of the liquid insulation.

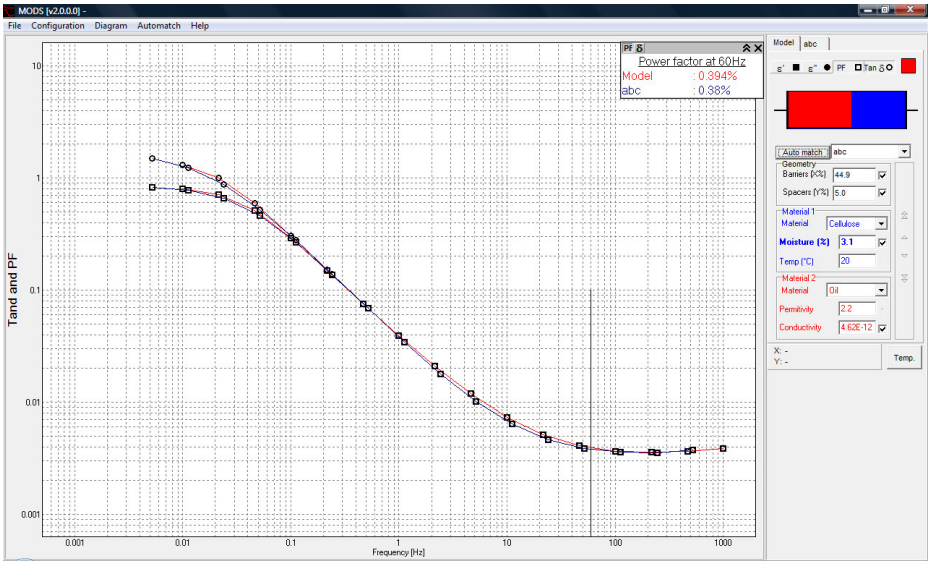

Figure 22 IDAX Test of COF-350 after filtration process - connection GST

	Capacitance	Moisture Content (%)	Oil Conductivity (S/m)	PF@60Hz (%)
GST	1.1E-10	3.1	4.62E-12	0.38

Table 3 IDAX test on COF-350 after filtration process

The tested unit shows improvement and acceptable parameters to get back into operation.

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Experience gathered through experimentation indicates a range of moisture concentration between 0.5 – 2.0% in new CTs after factory test. Power factor values as presented in international standards will vary in a range from 0.2 to 0.25% in brand new transformers and this value will increase with ageing of the units due to gas evolution and degradation of the insulation system. In accordance to standards, a value above 0.5% PF at the power frequency calls for additional testing procedures and, a value above 1% PF is a reason to remove the unit from operation. Normal construction of CTs does not provide piping, valves and fittings (PV&F) for oil filtration.

7 Conclusions

TBA

8 References

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